Part A: English Edition

Journal of Textiles and Polymers

Vol. 9, No. 3, 21-28, July 2021

http://dx.doi.org/10.48302/jtp.2021.136075

ORIGINAL PAPER

Multi-dimensional Analytical Base Method for Evaluating Camouflage Patterns

Elaheh Daneshvar, Mohammad Amani Tehrani*, and Fatemeh Zeighami

Received: 12 December 2020, Accepted: 17 April 2021

***Abstract*- Precise evaluation of camouflage patterns is very important to achieve an effective protective cover. Recently, researchers have focused on proposing computational methods for camouflage evaluation using algorithms of image feature extraction. Although the available indexes determine the similarity of camouflage patterns to the environmental background, they generally suffer from a lack of quantified camouflage principles. The main idea of this paper is to propose a new evaluation metric by defining seven camouflage factors to evaluate camouflage patterns. To this end, several conceptual factors of camouflage that are vital for a camouflage pattern were defined. Accordingly, if a pattern does not contain the mentioned camouflage factors, it cannot be considered as an effective protective pattern. In this regard, if a pattern comprises more of the camouflage factors, it has better efficiency in concealment. To indicate the performance of the proposed metric, we analyzed the effectiveness of different customary camouflage patterns using the fundamental factors to categorize them into three different classes including inefficient, moderately efficient, and efficient. The results showed that the camouflage evaluation with the proposed camouflage features is reliable and reasonable.**

***Keywords*: military uniform, camouflage factors, evaluation metric, quantitative method**

I. INTRODUCTION

Military uniforms are an unavoidable part of national authority and identity. Today, military uniforms have a camouflage effect to safeguard the army forces in battles. Although the early military uniforms had no camouflage pattern, the recently produced uniforms contain camouflage patterns due to the development of military tactics [1]. Therefore, the military forces attempt to produce more successful camouflage patterns concerning the strategic regions. In this regard, the evaluation of camouflage patterns is an important step to produce an effective camouflage pattern [2]. Researchers proposed different quantitative metrics based on image feature extraction to evaluate camouflage patterns [2-8].

Indeed, all the available evaluation methods of camouflage patterns are computable approaches based on the feature similarity between the camouflage pattern and its background image. For example, some researchers exploited the algorithms of image quality assessment to evaluate the effectiveness of a camouflage pattern for a background image [3,6,8,9]. Liming and Weidong proposed weight structural similarity (WSSIM) index based on the human visual model to calculate the similarity between a camouflage pattern and a background image. They also calculated several image features (e.g. mean of luminance, image entropy, and correlation length) between the camouflage pattern and the background image to understand what features of a camouflage pattern have the maximum effect on human detection performance [3]. Lin *et al.* proposed a camouflage similarity index by averaging the color differences between the pixels of the camouflage pattern and its background to assess the performance of camouflage patterns. The results showed that their proposed metric correlated well with the performance of human detection variables [8]. Lin *et al.* investigated the efficiency of the universal image quality index (UIQI) for evaluating the camouflage patterns and

E. Daneshvar, M. Amani Tehrani, and F. Zeighami
Textile Engineering Department, Amirkabir University of Technology, Tehran, Iran.

Correspondence should be addresses to M. Amani Tehrani
e-mail: amani@aut.ac.ir

revealed that the UIQI (a special case of SSIM index) correlated well with the human detection performance and it could be a potential camouflage assessment tool [6]. Xue *et al.* proposed the nonlinear fusion of several image features to quantitatively assess the degree to which the camouflage pattern and background differ in relation to background-related and internal features. They demonstrated that the proposed framework is an effective method for evaluating a camouflage pattern design [7].

Since a camouflage pattern contains different features, such as background similarity, disruption, concealing, and deceiving, extracting image features for evaluating a camouflage pattern is not a comprehensive and accurate approach. In fact, existing metrics only quantitate (measure) the background similarity of a camouflage pattern while many other different factors affect the efficiency of a camouflage pattern. Therefore, all effective factors on camouflage efficiency should be considered in proposing an evaluation metric.

In this paper, we have proposed a new criterion by combining a quantitative metric and several critical camouflage factors to evaluate the camouflage efficiency of camouflage patterns. Seven fundamental principles of camouflage in nature are recognized and utilized for evaluating the common camouflage patterns. Six camouflage factors are determined qualitatively and the background similarity of camouflage patterns is calculated based on the best existing WSSIM index [3]. Therefore, we analyzed the effectiveness of different customary camouflage patterns based on these defined camouflage factors. Finally, the camouflage patterns were classified into three classes by scoring them based on the camouflage factors and the WSSIM index.

II. FUNDAMENTAL CAMOUFLAGE FACTORS

According to the camouflage principles in nature and properties of the human visual system, elementary features that are essential for a camouflage pattern can be identified. These features include element diversity in a pattern, element size, irregularity in the pattern, disruption, type of edges in the pattern, quantity of basic colors, and similarity to the background. As these features are variable, changing them in a pattern can affect the efficiency of a camouflage pattern.

A. Element Diversity in a Pattern

Cott proposed that the elements of a camouflage pattern should be various to resemble different objects of a scene, because a camouflage pattern with a single element may perceive as a single object [10].

B. Elements Size

There is not any exact information about the optimum size of camouflage pattern elements. This parameter is highly dependent on the size of the environment objects [11]. However, based on the multi-scale theory, it seems that the simultaneous existence of micro and macro elements is necessary to provide far and close distance camouflage.

C. Irregularity in the Pattern

Based on Cott's theory, the geometric relation between elements of a camouflage pattern is very important [10]. Besides, the vision system of the human is more sensitive to regularity compared with irregularity [12]. For example, the detection of a symmetric pattern is more convenient than an asymmetric pattern [13]. Therefore, the identification of an irregular pattern is more difficult than a regular pattern.

D. Disruption

Thayer proposed a disruptive coloration strategy that makes continuity between target and terrain by placing markings on the edges and near the outline of the target body [14]. A schematic illustration of disruptive comparing with distractive markings is shown in Fig. 1. As shown in Fig. 1, irregular stripes placed on the edges of the body provide the disruption feature. Moreover, the used elements should not be too small or too large to disrupt a pattern properly. In fact, the size of disruptive elements is dependent on the size of the human body and terrain objects [15,16]. Therefore, based on the human body size, the elements should have an optimum size to disrupt the camouflage pattern.

Distractive marking is a type of camouflage-making method, which delays recognition if it is used properly. This feature detracts the receiver's attention from the body outline preventing the determination of its form. Distractive marking uses conspicuous elements on the pattern and the size of elements should be small and the elements should not touch the body outline [11], whereas, in disruption, there are irregular stripes that contact the outline to break up the body outline [17]. However, it was revealed that distractive markings reduce camouflage efficiency and survival of the animal [18].

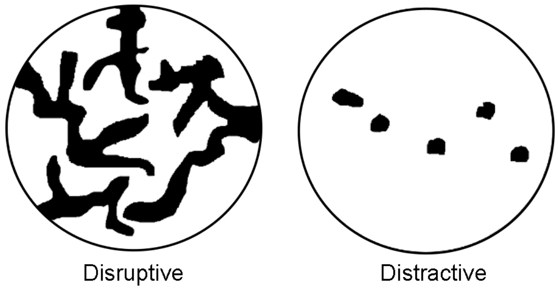


Fig. 1. Disruptive and distractive markings [17].

E. Type of Edges in the Pattern

Stevens *et al.* proposed the principle of surface disruption. According to the surface disruption theory, internal false edges in a pattern cause disruption and improve camouflage effectiveness [11]. Also, Egan *et al.* proved practically that edge enhancement promotes the effectiveness of a disruptive pattern by inducing a pictorial relief [19]. Furthermore, using color gradients for adjacent elements makes better color mixing and generates more effectiveness. Therefore, using internal false edges and color gradients simultaneously make a better camouflage effect.

F. Quantity of Basic Colors

Due to the background matching strategy, the colors of a camouflage pattern should be similar to random colors of the terrain [20]. As for color mixing at far distances [21] and camouflage in different scales, the average of the pattern colors should be equal to the average of the terrain colors. Therefore, if the pattern colors match more objects of the terrain, the camouflage efficiency is increased.

G. Similarity to Background

According to the theory of background similarity, shape, size, color and spatial distribution of a camouflage pattern should resemble the background to gain better efficiency. Since the weighted structural similarity (WSSIM) index [3] was suggested based on the human visual system and structural distortion measurement [22], the WSSIM index is an appropriate criterion to quantify the background similarity factor. Additionally, it has been proven that the SSIM index has a better correlation with subjective rating than error-based methods [22]. Also, the efficiency of the WSSIM index for evaluating the camouflage patterns has been investigated and revealed that the WSSIM index correlated well with the human detection performance [6].

III. IMPLEMENTATION

A. Collection of Camouflage Patterns and Background Images

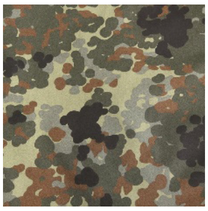
To develop the proposed metric, several famous camouflage patterns, namely Rainy, Splinter, Flecktarn, Frog-skin, Tiger-stripe, Woodland, Digital, and Multicam [23,24] were collected. The images of these camouflage patterns were downloaded [23] in JPG format with dimensions of 600×600 pixels. It must be noted that the selected patterns are common examples of designs used by the military forces. Selected camouflage patterns that are produced for woodland terrains are shown in Table I.

As for calculating the WSSIM of camouflage patterns, commonly the efficiency of a camouflage pattern is determined for specific environments, so, the appropriate images of the desired environments were captured. A Canon PowerShot G12 camera was used for capturing different images of woodland terrains in Iran. The images were used in sRGB color space with JPG format and dimension 3640×1535 pixels. The three selected background images are shown in Fig. 2. It must be noted that the exposure settings of backgrounds 1 and 2 were f/4 and 1/1250 s at ISO-200, and the settings of background 3 were f/6.3 and 1/250 s at ISO-100. In addition, all images were taken at 1:30 PM on a sunny day.

B. Evaluation of Camouflage Patterns

Based on the first six fundamental camouflage factors, i.e. element diversity, elements size, irregularity, disruption, type of edges, and colors quantity, each camouflage pattern

TABLE I
EXAMPLE CAMOUFLAGE PATTERNS OF MILITARY UNIFORMS

Pattern name	Rainy	Splinter	Flecktarn	Frog-skin
Image of pattern				
Pattern name	Tiger-stripe	Woodland	Digital	Multicam
Image of pattern				

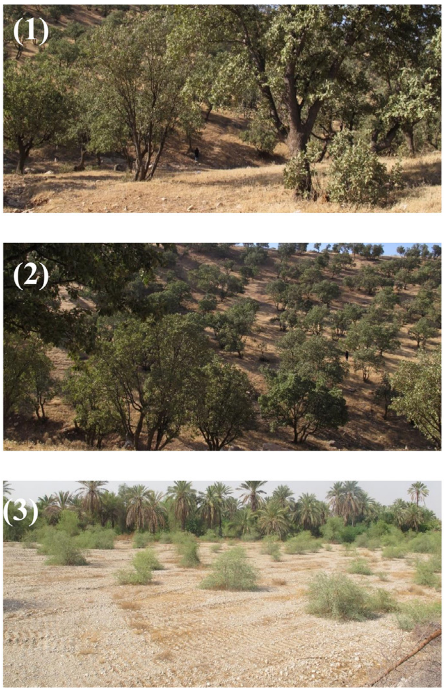


Fig. 2. Different selected background images: background (1), (2), and (3).

was analyzed to see whether it owned the defined factors. Then, to determine the seventh factor i.e. background similarity, the mean of WSSIM index for each camouflage pattern against 3 different background images was calculated. Finally, by scoring each camouflage pattern based on defined factors, they were classified into three classes including inefficient, moderately efficient, and efficient classes. The patterns were classified as inefficient if the total score was less than 5. If 4<total score<7; so the patterns are categorized as moderately efficient, and if a pattern obtains 7 factors it is classified as efficient.

B.1. Calculating WSSIM Index

Structural Similarity (SSIM) index [22] is a common index to measure the similarity between the reference and distorted signals. As for camouflage evaluation, the reference signal referred to the background image and the distorted signal is a camouflage pattern. Let x and y are the camouflage pattern and background images, respectively. The SSIM index is based on the computation of three terms, namely the luminance term, the contrast term, and the structural term which are shown in Eqs. (1) to (3), respectively [22]:

$$l(x,y)=\frac{2\mu_x\mu_y+C_1}{\mu_x^2+\mu_y^2+C_1} \tag{1}$$

$$c(x,y)=\frac{2\sigma_x\sigma_y+C_2}{\sigma_x^2+\sigma_y^2+C_2} \tag{2}$$

$$s(x,y)=\frac{2\sigma_{xy}+C_3}{\sigma_x\sigma_y+C_3} \tag{3}$$

Where, μ_x and μ_y are the mean of pixels intensity of camouflage pattern and background images, respectively. σ_x, σ_y, and σ_{xy} are the standard deviations and cross-covariance of pixels intensity for camouflage pattern and background images, respectively. As the used images are True Color images, pixel intensity refers to the intensity value in each channel, i.e. red, green, and blue channels. C_1, C_2, and C_3 are regularization constants to avoid instability for image regions where the local mean or standard deviation is close to zero.

According to Eq. (4), the overall index is a multiplicative combination of the three defined terms:

$$SSIM(x,y)=l(x,y)c(x,y)s(x,y) \tag{4}$$

The value range of SSIM is [-1, 1], and if x=y, the SSIM obtains the top value of 1 [25]. Therefore, lower SSIM means that the similarity of camouflage pattern with background image is minor. While the higher SSIM index shows more similarity of camouflage pattern with the background image. As the size of the camouflage pattern and the background image is not equal, Liming and Weidong [3] proposed Weighted-SSIM (WSSIM) index to calculate the similarity between a camouflage pattern and background image. The camouflage pattern is compared with each block of the background image with the same size to get the whole evaluation result according to Eq. (5):

$$WSSIM(x,y)=\frac{1}{M}\sum_{j=1}^{M}w_j SSIM(x_j,y_j) \tag{5}$$

Where, w_j is the weight of different blocks of background and M is the sum of the blocks. We selected w_j=1 for all of the blocks. The WSSIM was calculated for each channel R, G, and B of a camouflage pattern and background images distinctly and finally, the mean of three channels (R, G, and B) was calculated and presented as WSSIM for each pattern. To extract the RGB values from images and calculate the WSSIM index, we used Matlab Mathworks R2014a.

IV. RESULTS AND DISCUSSION

A. Quantitative Analysis of Camouflage Patterns

The SSIM index for the combination of different background images was calculated and the results are shown in Table II. If two images were identical, the SSIM gets 1, e.g. the SSIM index of background 1 with background 1 obtains 1 as seen in Table II. However, the SSIM of background 1 with background 2 obtained

TABLE II
SSIM INDEX FOR EVERY TWO BACKGROUND IMAGES

	Background 1	Background 2	Background 3
Background 1	1	0.271	0.308
Background 2	0.271	1	0.292
Background 3	0.308	0.292	1

0.271 that indicates these two background images are not exactly similar. For other backgrounds (Table II), the similarity of different backgrounds to each other is 0.308 and 0.292 that indicates the selected backgrounds were not similar. Our goal was to calculate the WSSIM of camouflage patterns for dissimilar background images. So, we can analyze the effectiveness of camouflage patterns for selected woodland images.

The WSSIM index for each camouflage pattern and three different background images are shown in Fig. 3. The average measure of WSSIM over different backgrounds shows that the MultiCam has the best performance between other patterns and the rainy pattern was the worst pattern. The MultiCam has the highest WSSIM for all backgrounds and the rainy has the lowest similarity to all backgrounds.

B. Analysis of Camouflage Patterns Based on Fundamental Camouflage Factors

The fundamental factors of camouflage for different custom camouflage patterns are shown in Table III. It was determined whether each camouflage pattern contains each defined feature or not (Table III). Detailed discussions for each pattern are presented in the following.

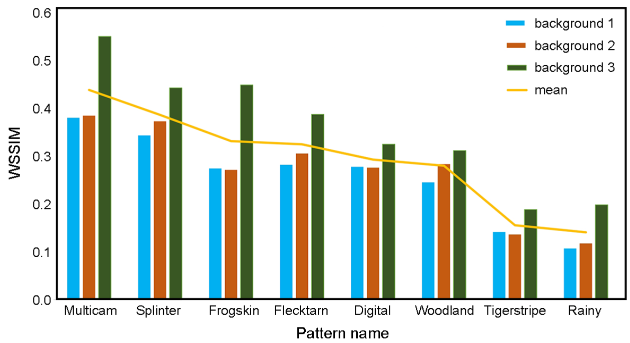


Fig. 3. WSSIM between each camouflage pattern and different backgrounds.

B.1. Rainy Pattern

The rainy pattern has a single color background with plenty of elements that resemble the falling rain. So, the rainy pattern is a single element design and does not have various elements. In terms of element size, this pattern contains micro-elements and due to the alignment of raindrops, this pattern is regular. As shown in Fig. 1, the rainy pattern does not disrupt the outline. On the other hand, the rain straits make sharp edges in the pattern, and thus they are not similar to the terrains objects. Considering Fig. 3, the WSSIM index of the rainy pattern was the minimum compared to other patterns. Some references noted that this pattern largely ineffective and rates poorly as camouflage in all environments [26]. Therefore, the rainy pattern can be rated as an inefficient pattern.

B.2. Splinter Pattern

This pattern consists of polygons that resemble splintered

TABLE III
FUNDAMENTAL FACTORS OF DIFFERENT CAMOUFLAGE PATTERNS

Pattern	Element diversity	Elements size	Irregularity	Disruption	Type of edges	Colors quantity	Background similarity (WSSIM)	Total score (out of 7)
Rainy	Single element	Micro pattern	Regular	No	Sharp	2	0.14	0
Splinter	Medium	Micro-macro pattern	Regular	Yes	Sharp	4	0.39	4
Flecktarn	Medium	Micro-macro pattern	Irregular	Yes	Smooth	5	0.33	5
Frog-skin	Medium	Medium pattern	Irregular	Yes	Sharp	4	0.33	4
Tiger-stripe	Medium	Micro-macro pattern	Irregular	Yes	Sharp	4	0.16	4
Woodland	High	Macro pattern	Irregular	Yes	Sharp	4	0.28	5
Digital	Medium	Micro-macro pattern	Irregular	Yes	Smooth	4	0.29	5
MultiCam	High	Micro-macro pattern	Irregular	Yes	Sharp and color gradient	7	0.44	7

shards of glass or other brittle matters and includes rain straits [27]. The element diversity of this pattern is not high as it contains only several polygons. This pattern can be classified as a micro-macro pattern due to the presence of rain straits. However, because of the alignment and regularity of the rain straits, they could not improve the camouflage efficiency. The contrast between elements is medium, so this pattern is not a high disruptive pattern. The pattern contains hard-edges between polygons and there are not any color gradients or smooth edges. This pattern has four colors to resemble the colors of leaf, wood, and ground but the shape of its elements is not similar to terrains objects. Therefore, the splinter pattern has many weak points based on the fundamental factors. So, we classified this pattern as an inefficient pattern whereas it has the second rank between other patterns based on the WSSIM index.

B.3. Flecktarn Pattern

Flecktarn has been issued by Germany and it means camouflage with spots [28]. This pattern consists of many spots that are similar to circles so that it is famous as a mottled pattern. Small spots join in some places and make larger spots. Therefore, Flecktarn has small and large spots, which create a medium diversity of elements shape. As for the element size, the presence of micro-macro elements provides multi-scale camouflage. The random distribution of spots over the background is a positive feature of this pattern. Due to joining spots with black and light colors, this pattern has a disruptive feature.

The spots in the Flecktarn pattern make a dithering effect that omits the sharp edges between colored patches. Five different colors of Flecktarn are suitable for temperate woodland terrain [28]. As the base element of Flecktarn is the spot, so the pattern does not match terrain objects effectively. This pattern has the fourth rank between other patterns based on WSSIM index. Therefore, based on the determined total score, this pattern was classified as moderately efficient.

B.4. Frog-skin Pattern

The Frog-skin pattern inspired by the disruptive skin of the frog and was the first effort of the United States military forces to generate a disruptive pattern [29]. Similar to the Flecktarn pattern, the Frog-skin is renowned as a mottled pattern. Therefore, this pattern contains many similar spots that consists of the medium diversity of elements. By focusing on the pattern, it is clear that the element size distribution is not very broad and the elements are apart from each other with sharp edges, so the spots do not form a multi-scale camouflage. While the mottles are randomly placed, the low diversity in the elements would be considered as a negative point in this kind of pattern. The elements shape is similar to the frog skin so it is not a good match for woodland terrains. Finally, this pattern obtained 4 factors out of 7, and thus it was placed in the inefficient category whereas this pattern has the third rank based on the WSSIM index.

B.5. Tiger Stripe Pattern

Tigerstripe's name is derived from the resemblance of the pattern to a tiger's stripes. The elements of this pattern are narrow stripes that look like brushstrokes of brown and khaki, and broader stripes of black over a green background. As these brushstrokes are repeated all over the pattern, it can be said that the element diversity is not very high. There are small and large stripes, which create a micro-macro pattern. The randomly drawn brushstrokes over the background create an irregular pattern. As for many broad black stripes, this pattern is a highly disruptive pattern that may destroy the background matching. Therefore, the contrast between pattern elements should be similar to the contrast of background objects. The different brushstrokes interlock rather than overlap and create sharp edges in the pattern [30]. The shape of elements is not very similar to the terrain objects. The WSSIM index of this pattern is very low comparing to other patterns. Therefore, this pattern achieved 4 factors out of 7, and thus it is an inefficient pattern.

B.6. Woodland Pattern

This pattern has different elements that are inspired by leaves and wood [31]. The size of elements of this pattern is large and it can be classified as a macro-pattern. So, this pattern is not successful at close ranges of distance because there is not any micro-element on it. The different elements placed irregularly in the pattern and based on Fig. 1 there are contrasting elements that disrupt the outlines. As for the type of edges, the internal edges of the pattern are sharp. There are four different colors including green and brown to resemble the leaf and wood, khaki color for matching the ground and black has a contrasting effect. The WSSIM index of this pattern was 0.28 that is a medium value between other patterns. The lack of microelements and color gradient are the imperfections of the woodland pattern. Therefore, as the Woodland pattern achieved 5 factors out of 7, it was considered as a moderately efficient pattern.

B.7. Digital Pattern

A digital pattern makes from square pixels and the pixels join together to make bigger patches. As the basic elements of the digital pattern are pixel and aggregated pixels, the element diversity of this pattern is not high. Two well-known properties of the digital pattern that made it popular are smooth edges that look like dithering to avoid sharp edges formation and micro-macro pattern to provide multi-scale camouflage. The pixels join together randomly in some places of the pattern to avoid regularity but the use of square pixels may create a little regularity in the pattern. This pattern has internal contrasting colors i.e. black and khaki colors, which provide disruption. Four colors in this pattern are similar to terrain colors but the square shape is not a good match for woodland objects. Eventually, it should be noted that the operational wars proved that the digitalization of a pattern is not an effective property for camouflage patterns [32]. However, it can be concluded that the digital pattern is moderately efficient, as it obtained 5 scores out of 7.

B.8. MultiCam Pattern

This pattern contains many different elements that have various sizes so that this pattern is a micro-macro pattern and provides multi-scale camouflage. The elements of the pattern are irregular and distributed randomly over the background. There are light and dark colors in the pattern that makes contrasting elements and cause a disruption effect. The internal edges of this pattern are sharp and smooth. Indeed, there are color gradients in this pattern; while other patterns do not have this feature. Furthermore, the pattern contains seven different colors, which is the maximum quantity of colors between other patterns that make more resemblance to the objects of terrains. MultiCam has the first rank between the selected patterns based on the WSSIM index. Consequently, the MultiCam pattern achieved the maximum score i.e. 7, and thus it is an efficient pattern.

V. CONCLUSION

In this study, we extracted the principles and strategies of camouflage in nature and named them as camouflage fundamental factors. Therefore, we proposed a novel approach based on the defined factors to evaluate the effectiveness of the camouflage patterns. In practical test of our idea, a dataset of customary camouflage patterns and woodland terrain images were collected and their effectiveness was determined based on the level of camouflage factors and WSSIM index. It was concluded that an efficient camouflage pattern should contain several camouflage factors such as various elements, micro-macro pattern, internal irregularity, disruption, sharp and color gradient, and background similarity. Furthermore, the results showed that quantitative methods like WSSIM only cover one camouflage factor i.e. background similarity. For example, despite the high WSSIM index of some camouflage patterns, they are classified as inefficient patterns as they do not contain sufficient camouflage factors. In fact, the computable indexes are valuable for evaluation but they are insufficient, as they do not cover all the requirements of camouflage and concealment. A computable method like WSSIM that calculates the structural similarity based on the pixel intensity of two images is not an exact method for evaluation of camouflage effectiveness. Therefore, to perform an accurate evaluation of camouflage patterns, the researchers should consider the fundamental features of camouflage in addition to the similarity index of pattern and background image. Finally, our research enables new insights into the camouflage evaluation methods to present a more precise computable algorithm by quantifying the fundamental camouflage factors.

REFERENCES

[1] M. Friškovec, H. Gabrijelčič, and B. Simončič, “Design and evaluation of a camouflage pattern for the Slovenian urban environment”, *J. Imaging Sci. Technol.*, vol. 54, no. 2, 2010. doi:10.2352/J.ImagingSci.Technol.2010.54.2.020507

[2] X. Feng, C. Guoying, H. Richang, and G. Jing, “Camouflage texture evaluation using a saliency map”, *Multimed. Syst.*, vol. 21, no. 2, pp. 169-175, 2015.

[3] S. Liming and G. Weidong, “A new camouflage texture evaluation method based on WSSIM and nature image features”, In: *Proceedings of the International Conference on Multimedia Technology*, Ningbo, China, 2010.

[4] H. Arsenault and P. Garcia-Martinez, “Intensity-invariant nonlinear filtering for detection in camouflage”, *Appl. Opt.*, vol. 44, pp. 5483-90, 2005.

[5] A. Ramli, M. Asri, and D. Sathyamoorthy, “Quantitative evaluation of camouflage patterns on textile materials using fractal analysis”, *J. Def. Secur.*, vol. 3, pp. 87-99, 2012.

[6] C.J. Lin, C.-C. Chang, and B.-S. Liu, “Developing and evaluating a target-background similarity metric for camouflage detection”, *PLOS One*, vol. 9, no. 2, pp. e87310-e87310, 2014.

[7] F. Xue, C. Yong, S. Xu, H. Dong, Y. Luo, and W. Jia, “Camouflage performance analysis and evaluation framework based on features fusion”, *Multimed. Tools Appl.*, vol. 75, no. 7, pp. 4065-4082, 2016.

[8] C. Lin, C.C. Chang, and Y.H. Lee, “Developing a similarity index for static camouflaged target detection”, *Imaging Sci. J.*, vol. 62, no. 6, pp. 337-341,

2014.
[9] S. Nyberg and L. Bohman, “Assessing camouflage methods using textural features”, *Opt. Eng.*, vol. 40, no. 9, pp. 1869-1877, 2001.
[10] H.B. Cott, and J. Huxley, “Adaptive Coloration in Animals”, England: Methuen & CO LTD, 1940.
[11] M. Stevens and S. Merilaita, “Defining disruptive coloration and distinguishing its functions”, *Philos. Trans. R. Soc. B*, vol. 364, no. 1516, pp. 481-488, 2009.
[12] F. Xue, F. Wu, J. Wang, and Y. Hu, “Camouflage texture design based on its camouflage performance evaluation”, *Neurocomputing*, vol. 274, pp. 106-114, 2018.
[13] I.C. Cuthill, M. Stevens, A.M.M. Windsor, and H.J. Walker, “The effects of pattern symmetry on detection of disruptive and background-matching coloration”, *Behav. Ecol.*, vol. 17, no. 5, pp. 828-832, 2006.
[14] G.H. Thayer, *Concealing-coloration in the Animal Kingdom: An Exposition of the Laws of Disguise Through Color and Pattern*, Macmillan Company, 1909.
[15] M. Stevens, “Predator perception and the interrelation between different forms of protective coloration”, *Proc. R. Soc. B*, vol. 274, no. 1617, pp. 1457-1464, 2007.
[16] T.N. Sherratt, A. Rashed, and C.D. Beatty, “Hiding in plain sight”, *Trends Ecol. Evol.*, vol. 20, no. 8, pp. 414-416, 2005.
[17] https://en.wikipedia.org/wiki/Disruptive_coloration
[18] M. Stevens, K.L. Marshall, J. Troscianko, S. Finlay, D. Burnand, and S.L. Chadwick, “Revealed by conspicuousness: distractive markings reduce camouflage”, *Behav. Ecol.*, vol. 24, no. 1, pp. 213-222, 2012.
[19] J. Egan, R.J. Sharman, K.C. Scott-Brown, and P.G. Lovell, “Edge enhancement improves disruptive camouflage by emphasising false edges and creating pictorial relief”, *Sci. Rep.*, vol. 6, pp. 38274, 2016.
[20] I.C. Cuthill, M. Stevens, J. Sheppard, T. Maddocks, C.A. Párraga, and T.S. Troscianko, “Disruptive coloration and background pattern matching”, *Nature*, vol. 434, no. 7029, pp. 72-74, 2005.
[21] Y. Zhang, S.-Q. Xue, X.-J. Jiang, J.-Y. Mu, and Y. Yi, “The spatial color mixing model of digital camouflage pattern”, *Def. Technol.*, vol. 9, no. 3, pp. 157-161, 2013.
[22] W. Zhou, A.C. Bovik, H.R. Sheikh, and E.P. Simoncelli, “Image quality assessment: from error visibility to structural similarity”, *IEEE Trans. Image Proc.*, vol. 13, no. 4, pp. 600-612, 2004.
[23] https://military.wikia.org/wiki/List_of_military_clothing_camouflage_patterns
[24] L. Talas, R.J. Baddeley, and I.C. Cuthill, “Cultural evolution of military camouflage”, *Philos. Trans. R. Soc. B*, vol. 372, no. 1724, pp. 20160351, 2017.
[25] Y. Wang, “Survey of objective video quality measurements”, Computer Science Faculty Publications, 2006.
[26] https://en.wikipedia.org/wiki/Rain_pattern
[27] https://camopedia.org/index.php?title=Splinter
[28] https://military.wikia.org/wiki/Flecktarn
[29] https://en.wikipedia.org/wiki/Frog_Skin
[30] https://military.wikia.org/wiki/Tigerstripe
[31] https://en.wikipedia.org/wiki/U.S._Woodland
[32] S. Mollicchi, “Flatness versus depth: A study of algorithmically generated camouflage”, *Secur. Dialog.*, vol. 48, no. 1, pp. 78-94, 2017.